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VISUAL AUGMENTATION SYSTEM (VAS) LABORATORY DEMONSTRATION AND TEST RESULTS

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Boeing Vertol Company

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This document describes the laboratory demonstration of the Visual Augmentation System (VAS) and components, later installed in the Model 347 helicopter, and the results of tests of operational parameters pertinent to the performance and suitability for in-flight evaluation; i.e., TV camera functions and optical characteristics such as focus, field of view, sensitivity, linearity resolution and vibration, electromagnetic compatibility,

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environmental tolerance.

Based on the results of the tests and demonstrations, it was concluded that the VAS was suitable for use in the flight evaluation test program.

EUSTIS DIRECTORATE POSITION STATEMENT

The objective of this effort was to demonstrate, under laboratory conditions, the suitability of installing a modified Cobra Night Fire Control System (CNFCS) in a model 347 helicopter and its use therein for in-flight evaluation as a visual augmentation system for the Heavy Lift Helicopter. Full-scale hardware was fabricated to predetermined criteria. Operational parameters relating to system performance were tested to establish suitability for flight evaluation.

The results of the test program identified limitations in the optical elements relating to the O.P.-Fish-eye 180-degree field of view and the effects of hot spots as reflected by the illuminator beam on the display console. In all other aspects, test results were acceptable.

This Directorate concurs with the conclusions presented herein.

The technical monitor for this effort was Mr. Jules A. Vichness, Heavy Lift Helicopter Project Office, Systems Support Division.

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INTRODUCTION

The Visual Augmentation System (VAS) procured for the HLH Advanced Technology Components program is basically a closed-circuit TV system. It has a wide field of view and is operable over a very wide dynamic range of scene illumination.

The hardware consists of a Cobra Night Fire Control System (CNFCS) television camera, modified to

1. eliminate the azimuth gimbal,
2. change and add lens elements,
3. change from 525-line scan to 875-line scan, and
4. utilize a new 875-line display (monitor).

The CNFCS illuminator has been changed from a rectangular uniform field to a circular uniform field. A new control panel has been provided and an Electronics Interface Unit (EIU) is included to generate and position cargo coupling symbology on the display, by video mixing with the TV signal.

DESCRIPTION OF VISUAL AUGMENTATION SYSTEM COMPONENTS

Figure 1 shows the visual augmentation system as installed on the Model 347 helicopter. The components illustrated are:

Illuminator (lower left)
Display and Control Panel (upper left)
Electrooptical Sensor (upper right)
Power Distribution Unit (lower right)
TV Signal Processor (lower right)
Servo Unit (lower right)
Electronic Interface Unit (lower right)

ILLUMINATOR

The illuminator has been constructed from the basic CNFCS illuminator by changing the beam forming lens assembly to provide a uniform 50-degree illumination and changing the IR filter to include the shorter wavelengths, making it semi-covert (low-level visible pink light).

DISPLAY

The VAS display is a 10-inch, 875-line, television monitor. The monitor is identical to the B-52 EVS monitor, with the exceptions that:

- The display has undergone expanded vibration testing in the range of 0-150 Hz to assure compatibility with helicopter operational environments.
- The CRT tube has been hand-picked to assure that maximum allowable beam spot size is not exceeded.
- The CRT tube face-plate has been gold-flashed to reduce EMI/RFI from the front of the tube which conceivably could interfere with low-frequency radio aids to navigation.

The display is designed to meet ambient lighting conditions of 5.83×10^3 foot-lamberts. It has controls for display intensity and contrast.

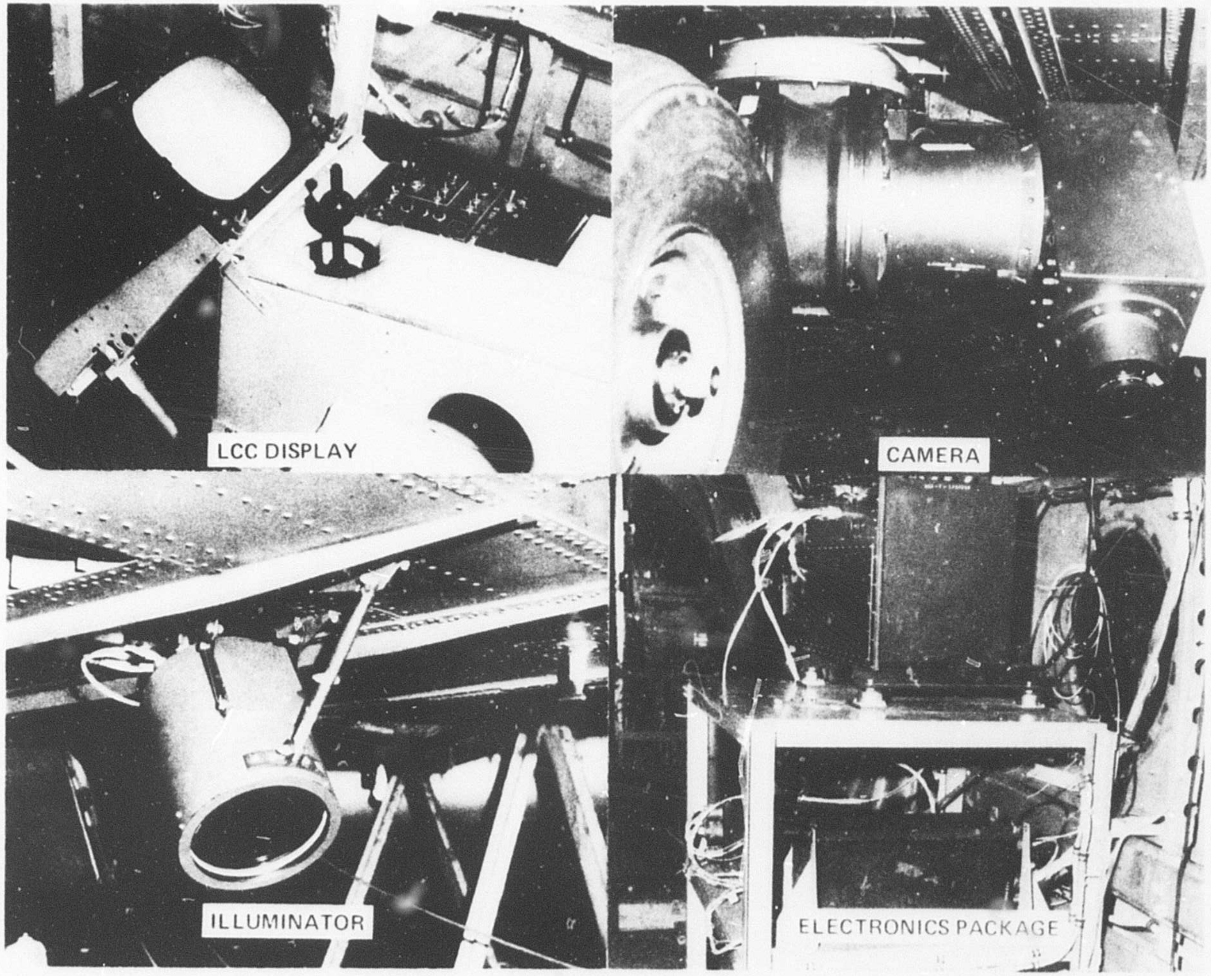

Figure 1. 347 VAS Components.

CONTROL PANEL

The control panel illustrated in Figures 1 and 2 contains the bulk of VAS controls.

SYS Power - This toggle switch energizes the complete VAS.

ILLUM - This toggle switch energizes the illuminator.

AFT - This alternate action push button selects the aft hook symbol and aft hook ground projection symbol for display.

CRT - This alternate action push button selects the center symbols for display.

FWD - This alternate action push button selects the forward hook symbols.

BRIGHT - This potentiometer controls symbol brightness on the monitor.

SELF-TEST - This illuminated momentary push button causes selected symbology to assume a predetermined self-test position.

CAMERA - This heading connotes the right side of the control panel to be used for camera control.

STOWING - This indicator lights green when the camera is stowing because of a minimum operating altitude of 7 feet or rear landing gear oleo compression.

STOW - 45° - Down - This synchro controls camera pointing angle. Down is a calibrated symbology position which enables symbology to appear on the monitor.

FOCUS - This center position spring-loaded toggle switch controls camera optical focus. It should be adjusted with optimum range and zoom set for minimum field of view or maximum optical magnification.

ZOOM - This center-position spring-loaded toggle switch allows optical zooming of the camera lens. "OUT" implies minimum magnifications or maximum field of view. "IN" implies maximum magnification or minimum field of view.

ALC/MAN - This toggle switch selects automatic level control of the camera or manual control of the camera. When in the manual mode "CAMERA GAIN" and "IRIS" are enabled.

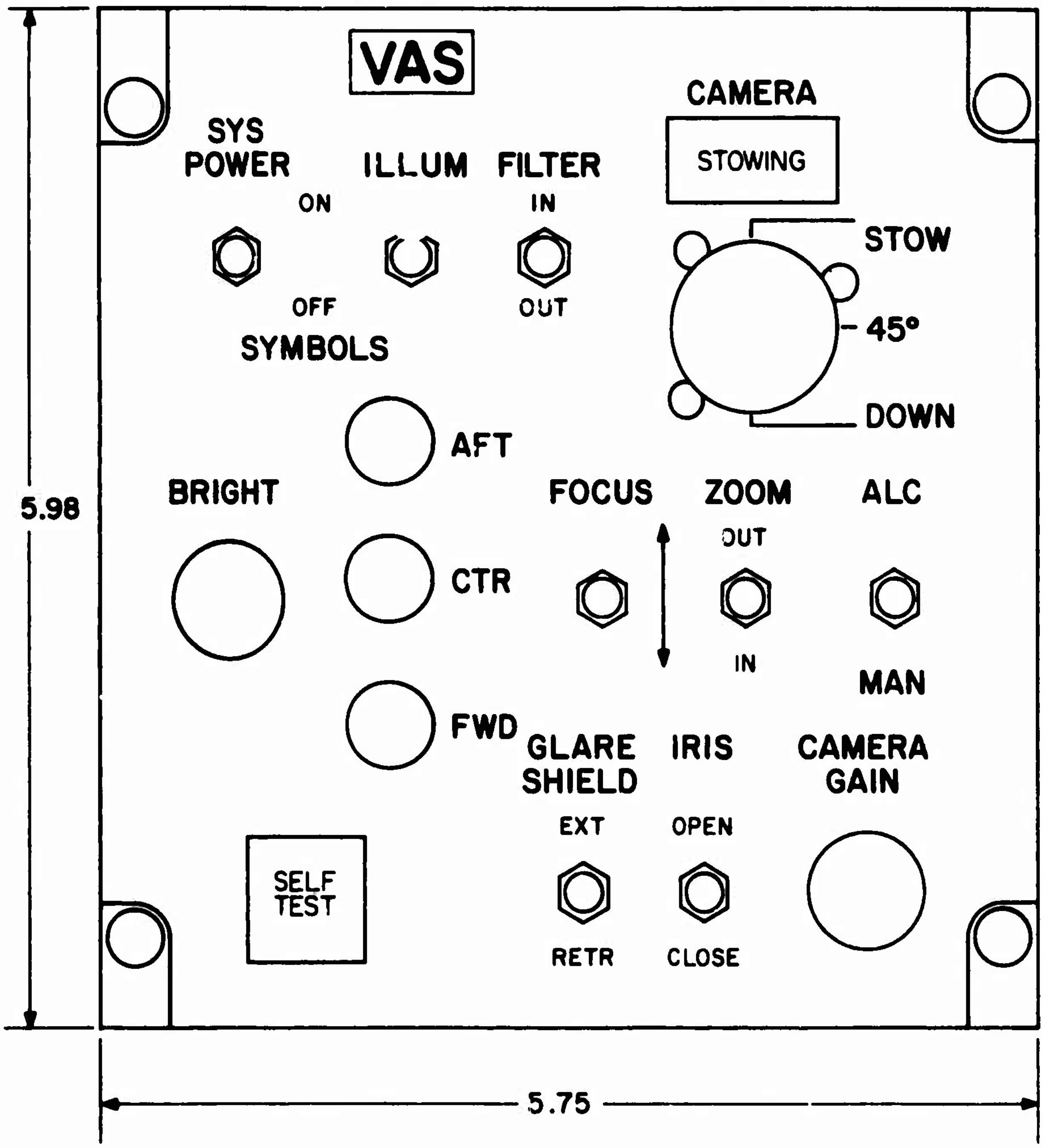

Figure 2. Control Panel.

CAMERA GAIN - This potentiometer controls high voltage on the camera intensifier tube, increasing this voltage increase gain of the tube.

IRIS - This center-position spring-loaded toggle switch controls camera iris. "Open" allows more light to enter the lens system.

GLARE SHIELD - This center-position spring-loaded toggle switch controls the glare shield. EXT causes shading of the maximum field of view periphery. This controlled shading will allow an improved ACC performance on the reduced (more interesting) field by eliminating peripheral highlights.

ELECTROOPTICAL SENSOR

The Electrooptical Sensor (EOS) is made up of the CNFCS elevation gimbal (modified), the CNFCS TV camera (modified) and housing, and a new camera optics assembly and counterweights.

The gimbal modifications were primarily:

1. removal of all unused hardware, and
2. limit switch positioning for "DOWN" and "STOW".

The TV camera modifications reversed the vertical scan to invert the picture and changed other minor circuits to assure compatibility with the new scan rate.

A new camera optics assembly was fabricated to integrate the VAS lens modules with the TV camera. It contains:

1. a folding mirror,
2. the zoom lens assembly with adjustable iris and focus,
3. filters, and
4. one of three interchangeable prime lenses; 220-degree fish-eye, 180-degree OP, or wide angle.

Counterweights are attached to the TV camera housing on the end opposite the optics assembly to balance the moment arm in the elevation plane.

POWER DISTRIBUTION UNIT

The Power Distribution Unit (PDU) is the CNFCS unit with minor wiring changes.

TV SIGNAL PROCESSOR

This unit is the CNFCS TV signal processor unit with wiring changes to accommodate the new symbol video and the VAS control functions.

SERVO UNIT

This unit is the CNFCS hardware modified to change the function of a transformer circuit.

ELECTRONIC INTERFACE UNIT

The Electronic Interface Unit (EIU) is the major new hardware procured for the VAS. It is a special-purpose digital computer which generates the cargo coupling position and vertical projection symbology video and mixes it with the TV video in the proper sequence to display it in the appropriate position on the monitor. It generates forward center and aft coupling position and vertical projection symbology as a function of aircraft attitude, altitude and coupling cable length. For the flight evaluation, cable length is manually selected and calibrated symbology is available for either wide-open 180-degree OP lens field of view or for narrowest 180-degree OP lens field of view.

LABORATORY TESTS AND DEMONSTRATION

On numerous occasions during the preliminary design and development, partial demonstrations of some of the system operations were conducted.

Final acceptance tests and demonstrations were conducted on the finished VAS prior to its delivery to Boeing Vertol. These tests were conducted at RCA in Camden, New Jersey, and witnessed by RCA engineering and quality control, Boeing Vertol engineering and quality control, and Defense Contract Administration Service Office personnel.

The tests and demonstrations can be categorized as follows:

- Optical tests to verify and calibrate the field of view, aperture, zoom range, distortion, filter characteristics and mechanical function of zoom control, iris control and filter insertion.
- Sensor and display component tests of physical characteristics (size, weight, etc.) and operational parameters (band width, resolution, sensitivity, etc.).
- Symbology generation, positional accuracy and calibration.
- System operational demonstrations.
- Environmental tests on fabricated components.

OPTICAL TESTS

Prime Lens Assemblies

Each of the prime lens modules was optically and mechanically aligned to the remainder of the system. The final adjustments yielded parameters summarized in Table 1. These assemblies include field lenses to interface with the zoom relay lens and mounting provisions to permit rapid interchange of prime lens assemblies.

Table 1. Optical Parameters

	Fish-Eye	OP Fish-Eye	Wide Angle
Focal Length	6.3 mm	10 mm	9.8 mm
Maximum Aperture	2.8	5.6	1.8
Maximum Field of View	220°	180°	130° (Note 1)
Formula $y = f(\theta)$	$y = 6\ \theta$	$y = 10 \sin \theta$	$y = 9.8 \tan \theta$
Primary Image Diameter	23 mm	20 mm	43.5 mm
Reference Magnification (Note 2)	1.23 x	1.41 x	1.20 x
Reference Zoom Focal Length	122 mm	106 mm (Note 3)	125 mm
Field of View Range	45 to 220	27 to 180	27 to 100 (ht.) 28 to 120 (diag.)

Note 1: Some vignetting and distortion occur at 130°, but maximum FOV used is 120° on diagonal.

Note 2: Reference magnification is that required for the maximum FOV to be presented on the display. For the Kinoptik, maximum FOV is 120° on diagonal limited by zoom relay.

Note 3: At the minimum zoom relay magnification of 1.20 x the 180° FOV does not fill the display height.

Neutral Density Filter

Between the prime lens assemblies and the zoom lens is the selectable neutral density filter pair. A zero density filter and a 2.0 density filter are provided for daylight attenuation as needed. The 2.0 density neutral filter characteristic is shown in Figure 3.

Also shown in Figure 3 are the filter characteristics of the precision hover sensor laser filter which is interposed between the zoom lens and the TV camera lens. The new filter used on the face of the illuminator to limit ocular visibility while emitting illumination of shorter wavelength than the laser filter cutoff is depicted by the third curve in Figure 3.

Zoom Lens Assembly

The zoom lens assembly has the following characteristics:

- Focus gear, total rotation, 272°
- Focus time (from 6 feet to infinity), 15 seconds
- Focal length, 25 mm to 125 mm
- Focus distance range, 67 inches to infinity
- Zoom time (25 mm to 125 mm), 11 seconds
- Iris diaphragm, total rotation, 109° (total closure)
- Iris aperture, f/2.6 to total closure
- Iris time (f/3.1 to f/22), 7 seconds
- Back focal length, 22.9 mm (0.90 inch)
- Rear clear aperture, 15 mm (0.59 inch)
- Front clear aperture, 63 mm (2.48 inches)
- Angular field of view (25 mm to 125 mm), 45° to 9°

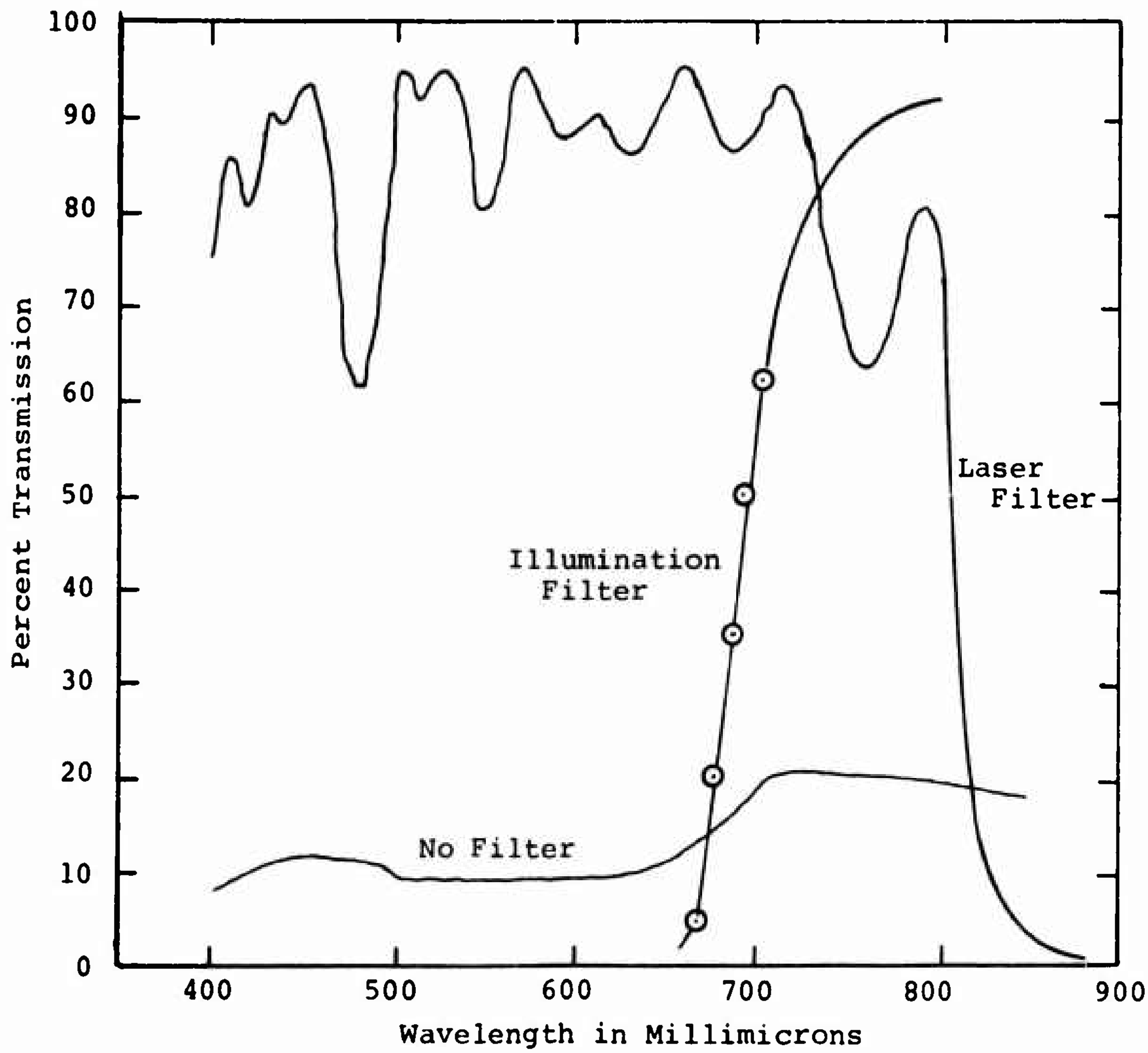

Figure 3. Filter Characteristics.

CNFCS TV Camera Lens

The last element in the optical path is the original CNFCS TV camera lens. This element is a 150 mm focal length lens assembly focussed on the I-SIT face plate of the TV camera. The only change made to this element was to use the CNFCS iris control as a glare shield in the new arrangement.

PHYSICAL CHARACTERISTICS

Each of the VAS components was subjected to a visual inspection to assure that hardware was firmly attached, electrical connections were properly made, and the new designs and major modifications conformed to the drawing callouts. Any discrepancies in workmanship, finish, etc., were corrected prior to delivery. The components weights were:

• Electronic Interface Unit (EIU)	125 lb
• Turret and TV Camera	*225 lb
• Power Distribution Unit (PDU)	10 lb
• Servo Amplifier	13 lb
• Control Panel	4 lb
• TV Signal Processor	25 lb
• Monitor (Display)	30 lb
• Illuminator (including relay)	20 lb
• Total VAS weight	*452 lb

* Weight including 220° prime lens and large balance weight on turret.

OPERATIONAL PARAMETERS

Significant parameters affecting the system performance were measured.

TELEVISION SYSTEM RESOLUTION

To determine system resolution at low light levels of 0.10, 1.0 and 10 lumen per square meter scene brightness (luminance), a 2-watt tungsten point source (Sylvania C2T) was used to illuminate the resolution targets. All resolution measurements were made at 16 feet from the OP-Fish-Eye lens. For the narrow field of view (32° x 32°) an enlarged USAF 1951 resolution chart print was used, and for the maximum field of view (180°) 3 bar groups were made with black photographic tape. Results for minimum field of view are shown in Table 2.

At the maximum field of view and 16 feet to the target, the resolution for luminance levels from 0.1 to 32 lumen per square meter is about 3.91 mrad per TV line which corresponds to 471 TV lines per display width. At this field of view, it was not possible to detect small changes in resolution with target luminance since a finely graded resolution chart was not available in the required size.

The magnification at the center of the field appears to be about 3.3 times higher for the narrow field of view than for the widest field of view. Thus, the widest field of view resolution of 3.91 mrad/TV line corresponds to 1.18 mrad/TV line at the narrow field of view. (See Table 2.)

TELEVISION SYSTEM SENSITIVITY

The minimum scene brightness required for the system is less than 0.01 lumen per square meter, corresponding to 1/4 moonlight illumination on a high reflectance target. At about 1000 lumen per square meter, corresponding to the illumination of a dull day, the ND2 filter will be required to overcome a severe granularity effect on the display. Large area scenes with average brightness corresponding to bright sunlight illumination were not displayed during these tests. The iris control should allow these scenes to be handled adequately. Small area medium to high brightness objects are somewhat troublesome in the system since they cause the surroundings to be nonviewable on the display and they also give images with high persistence or smearing during image motion.

TELEVISION SYSTEM BANDWIDTH

Video bandwidth response is primarily determined by the amplifier. The measured data plotted in Figure 4 indicates the -3-dB point to be 11.7 MHz.

Table 2. OP Lens Resolution - Minimum FOV		
Target Luminance	Limiting Angular Resolution	Limiting Resolution per Display Width
0.10 lm/m^2	1.33 mrad/TV line	420 TV lines
1.0	1.18	471
10	1.06	529
2000*	1.33	420

* At this luminance, the ND2 filter is required in the camera optical chain. Without it, very severe granularity in the display image is noted which decreases resolution by a factor of about 5.

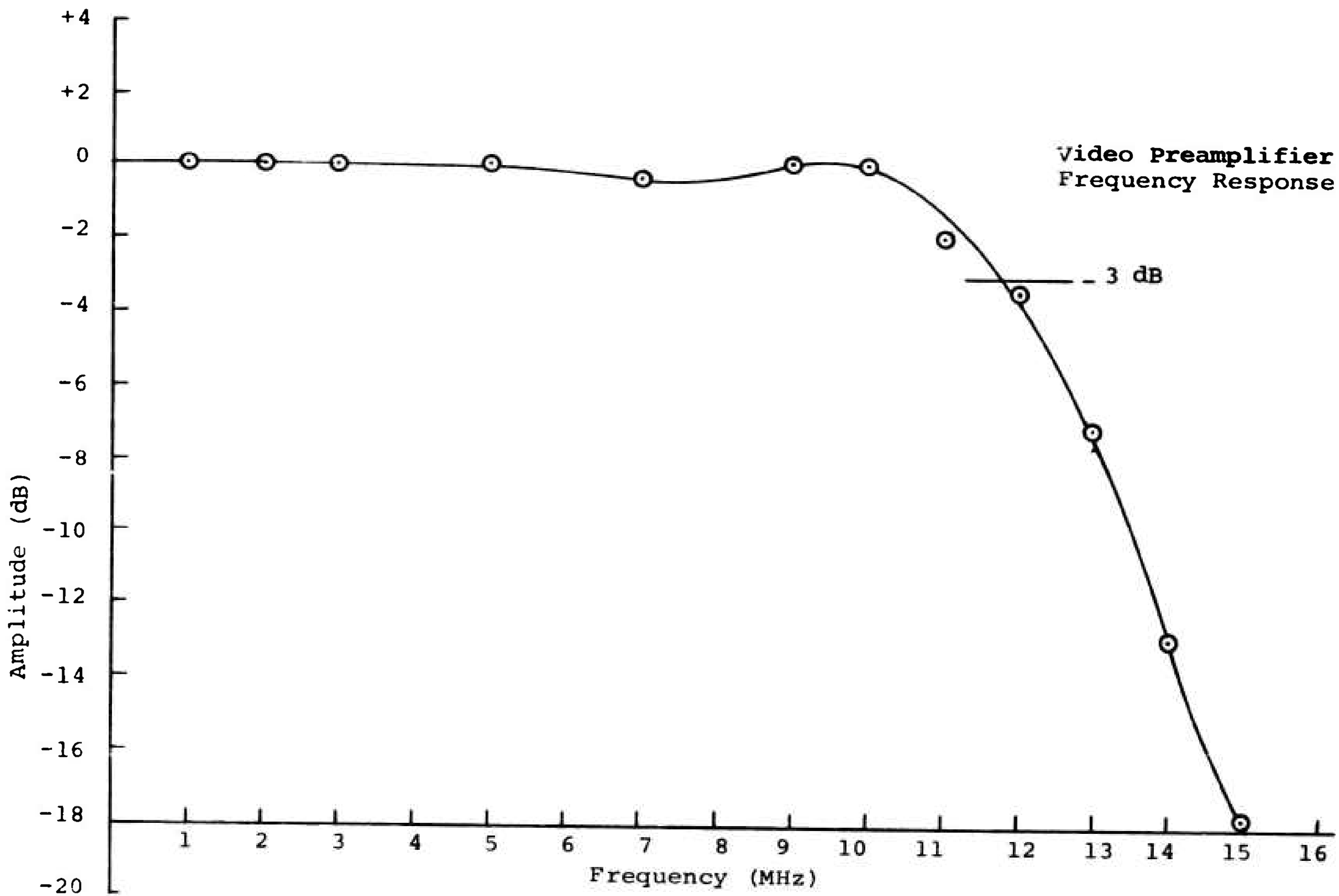

Figure 4. TV Video Bandwidth.

ILLUMINATOR BEAM PATTERN

The beam pattern of the illuminator was measured by a Weston Illumination Meter Model 756 after removing the RG695 i-r filter. The illuminance in foot candela was measured in a plane 10 feet from the beam forming lenses. Figure 5 shows the beam pattern and beam width. The beam is 43.6 degrees wide and its illuminance profile (through section A-A) is given in this figure for a flat plane 10 feet away. A central hot spot and one off-axis hot spot can be noted. The off-axis spot appears to be due to the effect of the vendor logo on the sealed beam source. It can be eliminated with a penalty of 12% illumination level by blocking the central lens element of the fly's eye beam forming lens array. The central hot spot appears to be due to many of the lens elements of the array. It could probably be eliminated by shortening the distance between the front and rear elements of the entire array, but this is a major retrofit operation for the present design.

A calibrated silicon photodiode was used to measure irradiance of the beam at a point corresponding to 48 foot candela illuminance. Without the i-r filter the irradiance measured 1.16 watts per ft^2 at 10 feet. The i-r filter reduces the silicon detector current by 30% and the irradiance by an even larger fraction. With the laser blocking filter (ML14B) from the camera optical system also in the beam, the silicon detector current is reduced by another 63%, resulting in a total reduction of 74% in detector current. The calculated irradiance is now 0.10W/ft^2. By assuming a uniform irradiance of 0.10W/ft^2 over an 8-foot diameter at a 10-foot distance (w - 0.50 sr), the effective i-r power output of the illuminator beam is 4.9 watts in the spectral range from 695 to 810 nm. Thus the illuminator effective i-r intensity is 9.8 watts per steradian over a "uniform" 44-degree beam width. Spectral transmission of the RG695 and the ML14B filters is shown in Figure 5. The spectral output of the illuminator is illustrated in Figure 3.

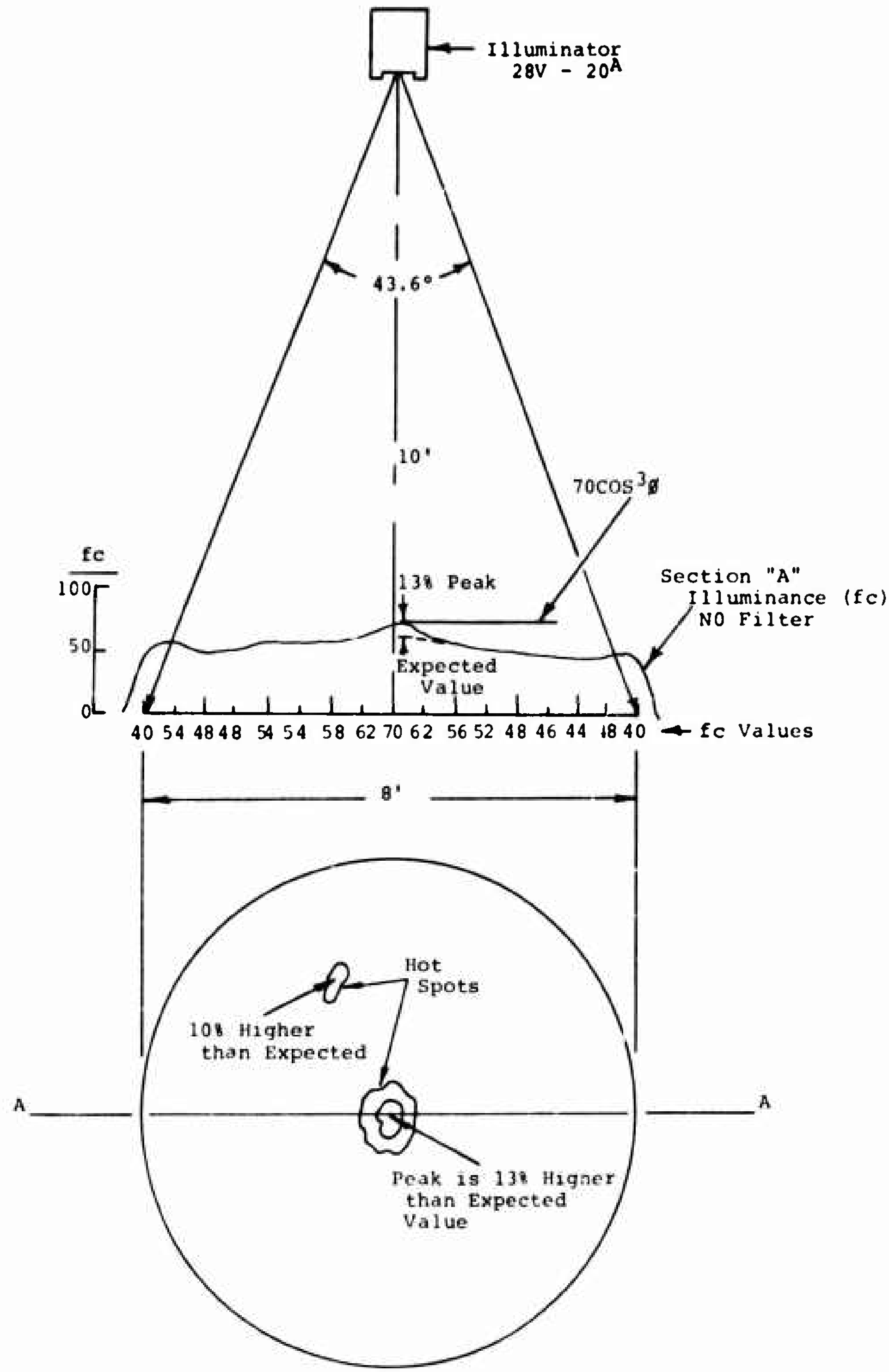

Figure 5. Illuminator Beam Pattern.

SYMBOLOGY GENERATION - CALIBRATION AND ACCURACY

The electronic interface unit is a special-purpose computer which determines the locations of the hooks and hook projections for input values of aircraft roll, pitch and altitude plus cable hook length. Three symbols assist in the location of the front, center or rear hook, and three symbols indicate the location of these three hooks projected to the ground. The corresponding locations of the respective hook symbols (squares) and hook projection symbols (crosses) relative to a video display of the load area are computed, generated, and displayed on the LCC station monitor.

Calibration and Accuracy Determination

The following procedure was used to calibrate the symbology:

Optical Alignment

- Establish turret base orientation to a waterline.
- Establish the optical centerline with existing CNFCS fiducial marks and a reference point at least 30 feet from the camera. The location of the reference point was determined by measurement. Rotation of the camera was used to establish the optical centerline of the CNFCS optics to the waterline.
- Install the relay lens assembly and verify its alignment by the calibration above. Operation of zoom and focus will verify assembly alignment. Upon installation of the 180° OP fish-eye lens, the resolution element displacement at center was approximately 1.6 inches at 30 feet.
- Depress the turret from horizontal to vertical. During motion, the fiducial marks tracked a straight line from the wall reference mark to a floor reference mark directly below the lens assembly. The track described was marked and used to lay out the hook cable position at the floor level. The geometry of the turret, forward hook, center hook, rear hook and optical line of sight in the calibrated position was thereby determined.

Reference Point Generation

- A computer printout was used to generate the floor level projections of hook positions for various altitudes (H), hook lengths (L), pitch angles (Ø), and roll angles (θ) as illustrated in Figures 6 and 7.

- For a set (H), (L), (Ø), (θ) programmed into the EIU a 1:1 correspondence existed for a floor projection and the corresponding symbol generated by the EIU. This data was used to verify the EIU memory programs.

By manually inserting cable length and simulated altitude and angle inputs, the symbols were precisely positioned on the floor marks, and at this point the digital logic states of the Read Only Memory outputs and video generator were recorded by observing the state indicator lights built into the EIU. By comparing the resulting known digital position parameters with the program, the symbol accuracy was determined. By successive comparisons of simulated cable length and angle inputs and memory values with digital state readouts, tracking of symbology was determined. Similar digital state readouts were used to check the positioned accuracy of the symbols in the "test" mode.

Any positional errors in the digital logic were corrected by reprogramming the memories. These tests were performed for both zoom positions having calibrated symbology.

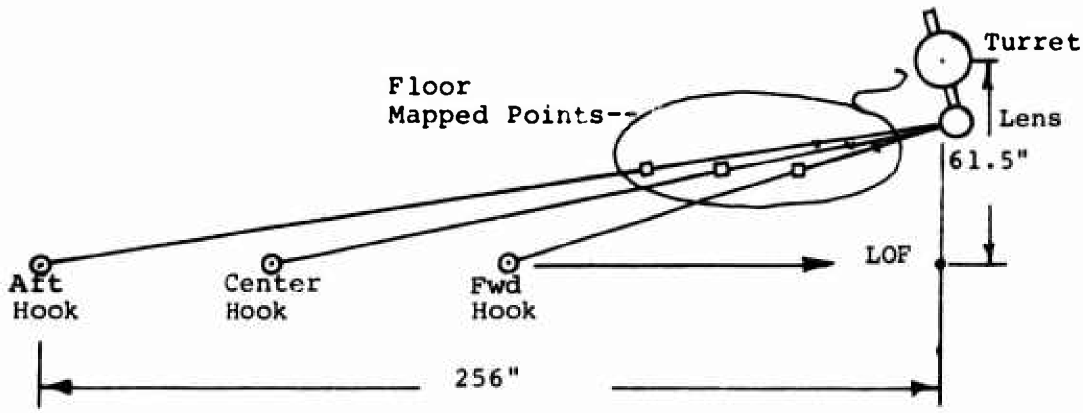

Figure 6. Symbology Test Layout - Top View.

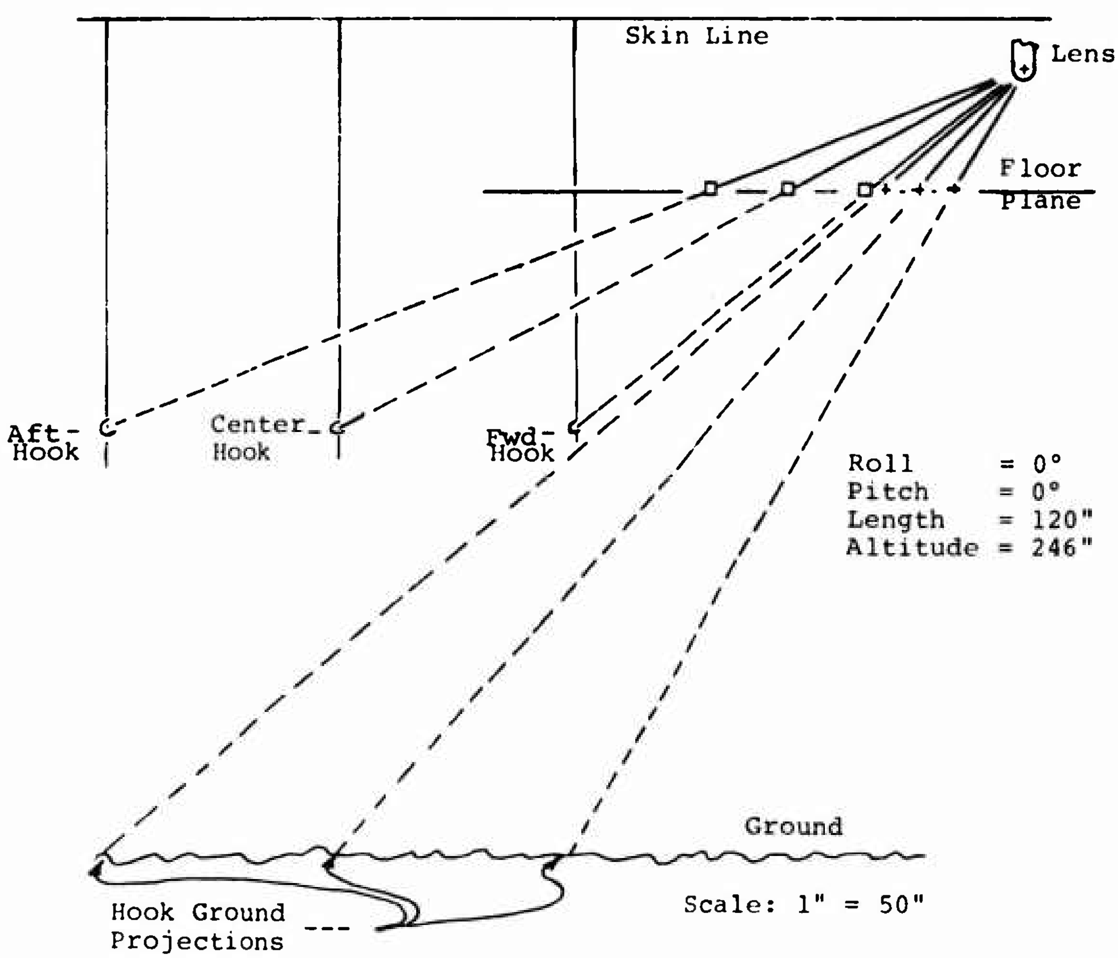

Figure 7. Symbology Test Layout - Side View.

SYSTEM OPERATION AND PERFORMANCE

After completing the physical inspection, environmental tests, and optical and electrical tests, the VAS components were assembled on a test fixture and, using the modified CNFCS cabling, the system was exercised through all of the control functions with each of the prime lens assemblies. A range of light levels was obtained by selective use of the artificial illumination utilized in the laboratory and by use of window shades and blinds to reduce natural illuminations.

In checking the operation of the symbology (with OP lens only), simulated altitude and aircraft attitude signals were supplied to the system input points.

The automatic stow function was also simulated with the altitude signal and with a manual switch to simulate the capsule retract switch.

ENVIRONMENTAL TESTS

Since the VAS, as procured, was intended for the ATC program (flight demonstration in 347 aircraft), only sufficient environmental testing for flight safety assurance was performed.

Also, since the original CNFCS hardware had been qualified for aircraft installation, only the EIU, the control panel and the significantly modified CNFCS hardware were tested (TV camera, gimbal and the illuminator).

Vibration tests and electromagnetic compatibility were the only tests deemed necessary to assure suitability for installation in the 347 aircraft.

Vibration Testing

Experience has shown that the most troublesome vibration effects occur at multiples of rotor RPM; therefore, particular attention was given during the vibration testing of the VAS components to frequencies corresponding to the nominal 347 rotor speed of 220 RPM; i.e., 3.66Hz, 7.33Hz, 14.7Hz (1/rev, 2/rev, 4/rev).

The procedure, test setup and laboratory recorded data are included in Appendix I.

Electromagnetic Compatibility

The VAS components were connected together on the test fixture using the modified CNFCS cabling. The system was tested for conducted emissions and susceptibility over a frequency range of 30Hz to 400MHz, with particular attention paid to the "clock" frequencies used in the automatic flight control computers for the 347 aircraft. The test procedure is included in Appendix II.

TEST RESULTS

OPTICAL TESTS

Image motion effects did not appear visually objectionable unless small and relatively high brightness objects (relative to the surround) were in the field of view. These led to very noticeable lag or tailing.

Geometric distortion of the optics due to the OP-fish-eye format ($y = 10\ M \sin \theta$) and the ISIT camera tube (pincushion distortion) are such that for a minimum field of view (32° x 32°) noticeable pincushion is evident on the display. For the maximum field of view as seen on the display, the full 180-degree field of the OP-fish-eye lens cannot be displayed. This is due to some misalignment in the optical chain which causes some vignetting.

Five bright specks are visible on the right side of the display.

Uniformity in the display will be degraded somewhat by the central hot spot of the illuminator beam.

COMPONENT TESTS

The visual physical inspection of the components uncovered several workmanship discrepancies. These were recorded, and corrective measures were completed and inspected prior to delivery.

SYMBOLOGY TESTS

Initially, there were some instabilities and positional inaccuracy in some of the six symbols caused by wiring errors and malfunctioning circuit components. Before acceptance, these discrepancies were corrected.

SYSTEM OPERATION TESTS

All the control functions were exercised for the camera, display, symbology and turret, and satisfactory functioning was obtained. The three prime lens assemblies were utilized and adjudged to perform essentially as expected. The system sensitivity was very good both with ambient light and with the illuminator. Two items to consider before flight testing were elimination of blanking during lens zoom and control panel illumination reduction; however, these items were not considered part of the acceptability criteria.

ENVIRONMENTAL TESTS

Vibration

The TV camera, the illuminator and the EIU were subjected to vibration tests (see Appendix I). Initially, the EIU indicated an undesirable vertical response in the 7Hz to 14Hz range. The vibration isolator mounting for the EIU was changed and the unit was retested. Satisfactory response was obtained on all units.

Electromagnetic Compatibility (EMC)

The VAS EMC was considered conditionally acceptable even though there were some data points obtained outside the limits of MIL-STD-461A. The critical frequencies around the automatic flight control clock frequencies and navigational radio frequencies were not affected.

The VAS was considered to be acceptable subject to confirmation of no adverse mutual effects after installation tests in the 347.

CONCLUSION

The VAS, as procured for the ATC program, is considered acceptable for use in the 347 demonstration flight program.

APPENDIX I
VIBRATION TESTS

With the system turned "on" for 15 minutes and functioning properly, the unit was subjected to vibration, conducted sequentially for each axis (longitudinal, lateral, and vertical, in that order) as follows:

Frequency	Amplitude	Mode	Duration
7.3 Hz	0.05 inch DA	Dwell	2 min
5-15 Hz	0.1 inch DA	Sweep	34 sec
14.7 Hz	0.05 inch DA	Dwell	2 min
15-150 Hz	± 1 g	Sweep	5 min

The consistency of vibration table references led to the inclusion of a single set of reference data in the report. Figures 8, 9, 10 and 11 illustrate the tested components setup for vibration testing.

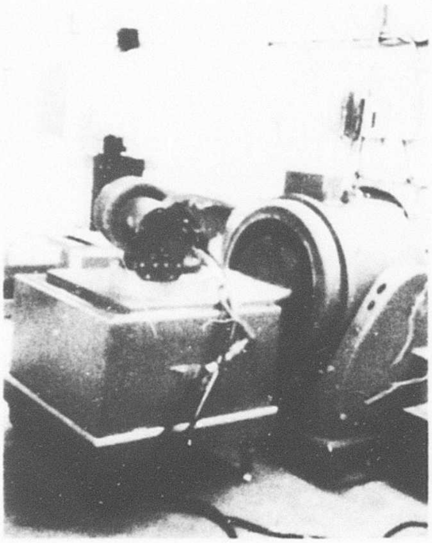

Figure 8. Turret and Sensor Vibration Test.

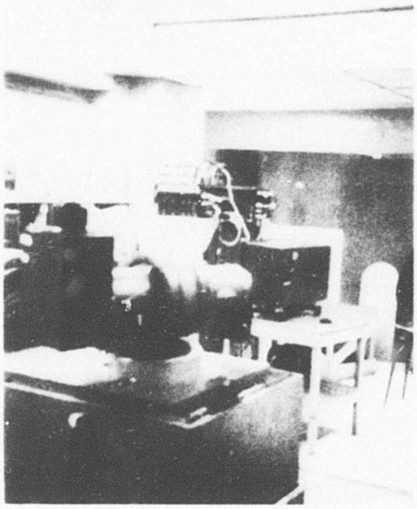

Figure 9. Turret and Sensor Vibration Test.

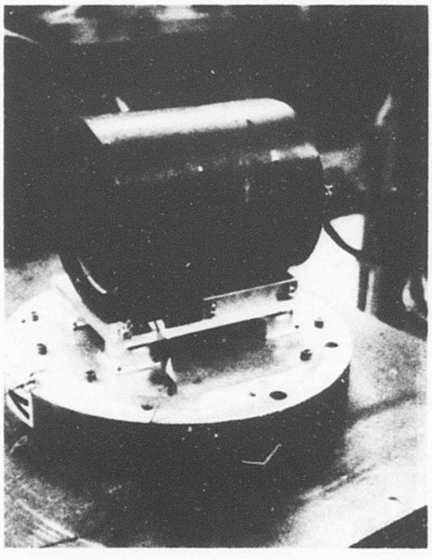

Figure 10. Illuminator Vibration Test.

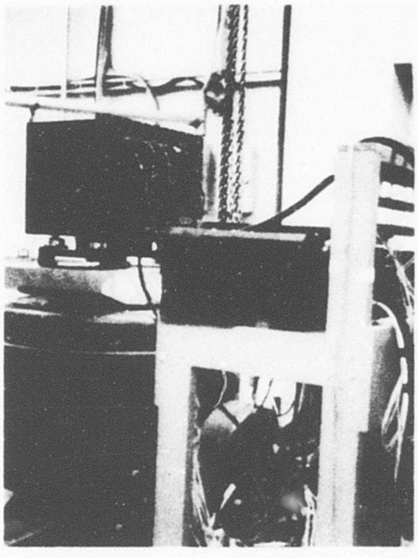

Figure 11. EIU Vibration Test.

APPENDIX II
ELECTROMAGNETIC COMPATIBILITY TESTS

Testing for electrical magnetic interference (EMI) for class ID equipment was carried out for the test categories specified in Table II of MIL-STD-461A. Spot tests across the spectrum were used to demonstrate the likelihood that a susceptibility problem does not exist. These are:

Emissions:

CE01	30 Hz to 20 KHz power leads
CE02	.03 MHz to 20 KHz control and signal leads
CE03	.02 MHz to 50 MHz power leads
CE04	.02 MHz to 50 MHz control and signal leads

Susceptibility:

CS01	.030 to 50 KHz power leads
CS02	.05 to 400 MHz power leads

Radiated Emissions:

RE04	.02 to 50 KHz mag field

Radiated Susceptibility:

RS01	.03 to 30 KHz mag field
RS03	14 KHz to 0.2 GHz

The equipment was operated for all these tests with subsystem operation monitoring to verify system operation. The tests were conducted with all subsystems operational.

COMMENTS

Alternating current power line testing for conducted emissions requires high pass test receiver filtering that is three times the power line frequency. This filter was unavailable at the time of test; hence, data reading below 1200 Hz are not conclusive.

All testing was performed with the original CONFICS cabling, not VAS cabling. It is expected that the shorter VAS cabling improves the EMI characteristics of the equipment.

The unavailability of test data on the furnished CONFICS components, the monitor and the navigation sensor-input simulator also necessitates tempering of interpretation of these data.